AUDITORILY ELICITED EVENT-RELATED DESYNCHRONIZATION (ERD) AND SYNCHRONIZATION (ERS) AS A METHOD FOR STUDYING CORTICAL CORRELATES OF COGNITIVE PROCESSES

CONFERENCES
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Abstract

The present paper reviews recent findings on event-related desynchronization and synchronization (ERD/ERS) elicited by complex auditory stimulation in association with cognitive tasks. The auditorily elicited ERD/ERS responses reflect higher-level cognitive processes such as attention, memory functions and conscious stimulus discrimination. The simultaneously recorded ERD/ERS responses of different EEG frequency bands differ as a function of time and cognitive task. Dissociations between the neural correlates of the processing of different types of auditory stimuli (e.g., verbal vs non-verbal, aggressive vs depressive etc.) can be assessed by means of the ERD/ERS technique. Narrow frequency band ERD/ERS analysis of the EEG thus offers a powerful tool for studying cortical activation patterns, and subtle differences between these as a function of various mental, cognitive, memory-related and emotion-related processes.

To participate in Basic Neuropsychological List

Introduction

Research on the electroencephalogram (EEG) can be traced back to 1875, to the work of Richard Caton. In 1929, Hans Berger discovered in the ongoing EEG the so-called alpha rhythm in man and was able to demonstrate that some of the activity originated in the brain itself and was not due to the activity of the scalp musculature (Berger, 1929). The rhythmic, ongoing EEG activity caused by the minor currents of the neural elements of the brain can be recorded simultaneously from multiple sites on the scalp or from the surface of the brain by means of the EEG. Although the EEG is one of the most widely used neuro- and psychophysiological measurement techniques, the nature of the generators in the brain responsible for the EEG are still largely a matter of debate (Steriade et al., 1990).

EEG frequencies are traditionally subdivided in frequency bands such as theta (4-8 Hz), alpha (8-12 Hz), beta (about 14-30 Hz) and gamma (around 40 Hz). During stimulation, the simultaneously recorded responses of different EEG frequency bands differ from each other (Klimesch et al., 1997; Pfurtscheller and Neuper, 1992; Steriade et al., 1990), and reflect different cognitive and /or mental processes or states (Boiten et al., 1992; Klimesch et al., 1994; Klimesch, 1996a; Klimesch et al., 1998; Dumont et al., 1999). It has been proposed that different neural generators are involved in the generation of different EEG frequencies (Fernández et al., 1998). For example, hippocampal neural activity is reflected within the theta frequency band (~4-8 Hz) (Burgess and Gruzelier, 1997) while the alpha rhythm (~8-12 Hz) is generated mainly by corticocortical and thalamocortical neural networks (Steriade et al., 1990; Klimesch et al., 1994; Klimesch, 1997).

Oscillations of different EEG frequencies are associated with different mental processes. Episodic memory processes seem to be reflected as oscillations in the EEG theta frequencies (~4-8 Hz) (Klimesch, 1996a). In contrast, 8-10 Hz alpha activity seems to be modulated as a function of attentional demands (Klimesch et al., 1992) whereas 10-12 Hz alpha activity is modulated by stimulus-related aspects, and/or semantic memory processes (Klimesch et al., 1994; Klimesch, 1996a; 1996b).

Event-related desynchronization (ERD) and synchronization (ERS)

The event-related decrease in EEG power is termed "event-related desynchronization" (ERD) (Pfurtscheller, 1977) while synchronization, or "event-related synchronization" (ERS) denotes the increase of in power (Pfurtscheller, 1992).

The quantification of ERD/ERS requires the comparison of two different experimental conditions. ERD/ERS is defined as the relative difference in EEG alpha power between the two conditions (Pfurtscheller et al., 1988). ERD/ERS is thus a "within-subject" measure of cortical activation and is expressed as a percentage. ERD is closely related to cortical activation and consciousness (Pfurtscheller, 1977; Pfurtscheller et al., 1988), whereas ERS reflects cortical areas at rest or in an idle state (Pfurtscheller, 1992).

ERD has been observed during visual stimulation (Aranibar and Pfurtscheller, 1978; Pfurtscheller et al., 1977; 1988; 1994; Pfurtscheller and Klimesch, 1991), during simple auditory stimulation (Pfurtscheller et al., 1977; Schulter et al., 1990), during voluntary movement tasks (Mohl and Pfurtscheller, 1991; Pfurtscheller and Aranibar, 1979; Pfurtscheller and Berghold, 1989; Pfurtscheller and Neuper, 1992) and also during cognitive and attentional tasks (Boiten et al., 1992; Dujardin et al., 1993; Dujardin et al., 1994; Klimesch et al., 1988; 1990; 1992; 1993; Pfurtscheller and Klimesch, 1990; 1992a; 1992b; Pfurtscheller et al., 1994; Van Winsum et al., 1984). Auditorily elicited ERD/ERS in association with cognitive processes has mainly been studied by Krause and co-workers (Krause et al., 1994; 1995; 1996; 1997; 1999; Karrasch et al., 1998; Lähteenmäki et al, 1999).

Auditorily elicited Event-Related Desynchronization (ERD) and Synchronization (ERS)

In 1994 Krause et al. (1994) reported that ERD was elicited in the lower (8-10 Hz) and the upper (10-12 Hz) alpha frequency bands during and after the presentation of short auditorily presented phrases which the subjects were instructed to memorize. In that initial study, it was hypothesized that the ERD observed in their study most probably reflected attentional processes or memory-related functions rather than auditory processing per se.

In 1995, Krause et al. (1995) examined auditorily elicited ERD/ERS in ten normal subjects using the Sternberg (1966) memory-search paradigm. The memory set consisted of four synthesized auditory vowels and the probe consisted of one auditory vowel. The subjects had to decide whether the fifth vowel was earlier presented in the memory set and then to indicate their answer by pressing a button on a response pad. The presentation of the memory set elicited a significant ERS in both alpha frequency bands. By contrast, the presentation of the probe elicited a significant ERD in both alpha frequency bands. Auditorily elicited ERD/ERS of the lower (8-10 Hz) and upper (10-12 Hz) alpha frequency bands has also been studied during an auditory memory task with synthesized instrument sounds, resembling those of different instruments, as stimuli (Krause et al., 1996). In that study also, the presentation of the memory set elicited ERS in both alpha frequency bands whereas the presentation of the probe elicited ERD in both alpha frequency bands. When the ERD/ERS responses for vowels and tones were compared (Krause et al., 1995) differences between the ERD/ERS of the 8-10 Hz and 10-12 Hz frequency bands were found for vowels only. This finding verified that the two alpha frequency bands differ in their reactivity to stimulus type. The presentation of vowels might have activated corresponding phonetic templates, not available for tones and timbre, which in turn might have made it possible to use template matching or to use multiple cognitive strategies for the encoding/retrieval of vowels. The 10-12 Hz frequency band exhibited greater overall ERD/ERS values as compared to the lower, 8-10 Hz frequency band.

Auditorily elicited relative alpha desynchronization and synchronization has been studied during speech perception. Krause et al. (1997) presented to their subjects a five-minute spoken text passage presented both forward and backward. While listening to the text forward, subjects were instructed to memorize the contents of the text. A significant effect for the stimulus type was observed so that listening to and memorizing the text elicited ERD whereas listening to the text backward elicited ERS. The significant interaction between frequency band and stimulus type indicated that the 8-10 Hz and 10-12 Hz frequency bands differed such that the 10-12 Hz frequency band exhibited reactivity to the presence of linguistic content while the 8-10 Hz band showed an unspecific response. The results from this study indicate that the auditorily elicited responses of the upper alpha frequency band are language-related, whereas those of the lower are not.

Auditorily elicited ERD/ERS has also been examined during an auditory lexical decision task (Karrasch et al., 1998). In this study, the stimuli were auditory presented Finnish words and pseudowords presented sequentially in pairs. The subjects were instructed to answer whether the two stimuli belonged to the same category of lexicality. The main finding of this study was that regardless of lexicality, the presentation of the first stimulus (encoding) elicited a significant ERS. The presentation of the second stimulus (comparison) elicited ERD which, however, varied in magnitude and latency as a function of stimulus type and previous stimulus type. Karrasch et al. (1998) suggested that the ERD observed in their study did not reflect primary auditory stimulus processing. The ERD/ERS observed in their study

most probably reflected subtle differences between lexical-semantic and phonological memory functions.

In 1999, Krause et al. (Krause et al., 1999) examined cortical correlates of semantic memory processes in the auditory stimulus modality by means of the ERD/ERS technique while the subjects were performing an auditory semantic matching task. The stimuli were abstract and concrete nouns which were presented sequentially in pairs. The task was to decide whether the two nouns belonged to the same semantic category or not. Krause et al. (1999) reported that the presentation of the first stimulus (encoding) elicited alpha ERS whereas the presentation of the second stimulus (semantic matching) elicited alpha ERD. Abstract nouns presented as the second stimulus elicited alpha ERD which was most prominent in the lower alpha frequency band whereas the presentation of a concrete noun as the first stimulus elicited ERS, most prominently in the upper alpha frequency band. Their findings demonstrate that the auditorily elicited ERD/ERS can reveal subtle differences in auditory information processing.

Semantic memory processes (encoding and comparison) seem to be reflected as varying responses in the two alpha frequency bands.

Auditorily elicited relative alpha desynchronization and synchronization has also been studied during music perception by Krause et al. (Krause et al., 1999). The subjects listened to two different five-minute musical excerpts, one popular and the other classical, presented both forward and backward. In this study, the ERD/ERS responses of the 8-10 Hz and 10-12 Hz were examined with regard to the "musicality" of the stimulation (forward vs. backward) as well as to its musical genre (popular vs. classical). The results from this study revealed that the ERD/ERS responses of the 8-10 Hz and 10-12 Hz frequency bands were dissimilar, dynamic, and dependent on stimulation type as a function of time. The differences in the ERD/ERS responses between the different musical genres were most prominent in the 10-12 Hz frequency band. The lower alpha responses were modulated as a function of time.

In 1999, Lähteenmäki et al. (Lähteenmäki et al., 1999) examined the long term effects of childhood cancer treatment on adolescent cancer survivors by means of auditorily elicited ERD/ERS. In that study (Lähteenmäki et al., 1999) it was observed that childhood cancer treatment had long-lasting effects on the ERD/ERS reponses, especially in the 8-10 Hz frequency band, being most pronounced in leukemia survivors. Lähteenmäki et al. (1999) concluded that such changes in this responses of this alpha frequency band might shed some light on the often reported attentional problems after cancer treatment.

The term "affective neuroscience" refers to the study of neural mechanisms associated with human emotions. Recently, Krause et al. (submitted manuscript) examined cortical correlates of emotional memory processes by means of ERD/ERS of the 4-6 Hz, 6-8 Hz, 8-10 Hz and 10-12 Hz EEG frequency bands while the subjects were performing an auditory memory task with emotion-related verbs as stimuli (aggressive, depressive and neutral verbs). In that investigation, all the studied frequency bands exhibited responsiveness to the emotional content of the auditory stimuli. The ERD/ERS responses of different frequency bands differed, however, as a function of time and memory task (encoding vs. retrieval). In the alpha frequencies (8-10 and 10-12 Hz), the retrieval of specifically aggressive and depressive verbs elicited ERD observed most prominently in the right hemisphere

electrodes. Krause et al. (Submitted manuscript) suggested dissociations between the neural correlates of the encoding and retrieval of different types of emotion-related auditory stimuli and that the ERD/ERS method is appropriate for assessing these. The results indicated that narrow frequency band ERD/ERS analysis of the EEG seems to offer a powerful tool for studying cortical activation patterns also during emotion-related processes.

Discussion

A review of the investigations in which the ERD/ERS technique has been used to study auditory information processing reveal that the auditorily elicited ERD/ERS reflect attentional and cognitive processes rather than auditory stimulus perception per se. The auditorily evoked ERD/ERS responses of several EEG frequency bands differ systematically from one another as a function of mental task. Additionally, the auditorily elicited ERD/ERS responses vary as a function of task demands such as encoding vs. retrieval and stimulus type.

Time and timing are the very essence of auditory information processing. The estimation and understanding of time intervals and/or duration are very essential capacities, e.g., when acquiring language. The ERD/ERS technique allows one to study the modulation of various EEG background rhythms in association with auditory stimulation, as a function of time. By means of this technique, it is possible to examine various aspects of the temporal integration of auditory information far beyond behavioural investigation methods.

To summarize, the simultaneous ERD/ERD analysis of several narrow frequency bands gives an opportunity to investigate the cortical complexity underlying human information processing capacities not only in association with various cognitive processes but also with emotion-related processes. In future studies, the findings presented in this paper might be of potential importance when utilizing similar, complex cognitive experimental paradigms on some clinical populations suffering from, e.g., biologically determined irregular memory processes (as in Alzheimer´s disease) and/or processing of emotions (as in depression and schizophrenia).

References

- Aranibar, A., & Pfurtscheller, G. (1978). On and off effects in the background EEG activity during one-second photic stimulation. Electroencephalography and Clinical Neurophysiology, 44, 307- 316.
- Berger, H. (1929). Ueber das elektroenkephalogramm das menchen. Archiv fuer Psychiatrie, 87, 527-570.
- Boiten, F., Sergeant, J., & Geuze, R. (1992). Event-related desynchronization: the effects of energetic and computational demands. Electroencephalography Clinical Neurophysiology, 82, 302-209.
- Burgess AP, Gruzelier JH (1997) Short duration synchronization of human theta rhythm during recognition memory. NeuroReport 8:1039-1042.
- Dujardin, K., Derambure, P., Defebre, L., Bourriez, J.L., Jaquesson, J.M., & Guieu, J.D. (1993). Evaluation of event-related desynchronization (ERD) during are cognition task: effect of attention. Electroencephalography and Clinical Neurophysiology, 86, 353- 356.
- Dujardin, K., Bourriez, J.L., & Guieu, J.D. (1994). Event-related desynchronization (ERD) patterns during verbal memory tasks. International Journal of Psychophysiology, 16, 17-27.
- Dumont M, Macchi MM, Carrier J, Lafrance C, Hébert M (1999) Time course of narrow frequency bands in the waking EEG during sleep deprivation, NeuroReport 10:403-407
- Fernández T, Harmony T, Silva J, Galán L, Diaz-Comas L, Bosch J, Rodriguez M, Fernández-Bouzas A, Yáñez G, Otero G, Marosi E (1998) Relationship of specific EEG frequencies at specific brain areas with performance. NeuroReport 9:3681-3687.

- Karrasch, M., Krause, C.M., Laine, M., & Lang, A.H. (1998). Event-related desynchronization during an auditory lexical matching task. Electroencephalography and Clinical Neurophysiology, 107, 112- 121.
- Klimesch, W., Pfurtscheller, G., & Mohl, W. (1988). ERD Mapping and long-term memory: The temporal and topographical pattern of cortical activation. In G. Pfurtscheller & F.H. Lopez da Silva (Eds.), Functional brain imaging, Toronto, Hans Huber, pp. 131-141.
- Klimesch, W., Pfurtscheller, G., Mohl, W., & Schimke, H. (1990). Event-related desynchronization, ERD-mapping and hemispheric differences for words and numbers. International Journal of Psychophysiology, 8, 297-308.
- Klimesch, W., Pfurtscheller, G., & Schimke, H. (1992). Pre- and post-stimulus processes in category judgement tasks as measured by event-related desynchronization. Journal of Psychophysiology, 6, 185-203.
- Klimesch, W., Schimke, H., & Pfurtscheller, G. (1993). Alpha frequency, cognitive load and memory performance. Brain Topography, 5, 241-251.
- Klimesch, W., Schimke, H., & Schweiger, I. (1994). Episodic and semantic memory: an analysis in the EEG theta and alpha band. Electroencephalography and Clinical Neurophysiology, 91, 428- 441.
- Klimesch W (1996a) Memory processes described as brain oscillations in the EEG-alpha and theta bands. PSYCOLOQUY 6:6 memory-brain.1. klimesch
- Klimesch W (1996b) Memory processes, brain oscillations and EEG synchronization.Int J Psychophysiol 24:61-100.
- Klimesch W (1997) EEG-alpha rhythms and memory processes. Int J Psychophysiol 26:319-340.
- Klimesch W, Russegger H, Doppelmayr M, Pachinger T (1998) Induced and evoked band power changes in an oddball task. Electroenceph Clin Neurophysiol 108:123-130.
- Krause, C.M., Lang, A.H., Laine, M., Helle, S., Kuusisto, M., & Pörn, B. (1994). Event-related desyncronization evoked by auditory stimuli. Brain Topography, 7, 107-112.
- Krause, C.M., Lang, A.H., Laine, M., Kuusisto, M., & Pörn, B. (1995). Cortical processing of vowels and tones as measured by event-related desynchronization. Brain Topography, 8, 47-58.
- Krause, C.M., Lang, A.H., Laine, M., & Pörn, B. (1996). Event-related EEG desynchronization and synchronization during an auditory memory task. Electroencephalography and Clinical Neurophysiology, 98, 319-326.
- Krause, C.M., Pörn, B., Lang, A.H., & Laine, M. (1997). Relative alpha desynchronization and synchronization during speech perception. Cognitive Brain Research, 5, 295-299.
- Krause, C.M., Åström, T., Karrasch, M., Laine, M., & Sillanmäki, L. (1999) Cortical activation related to auditory semantic matching of concrete vs. abstract words. Clin Neurophysiol.110, 1371-1377.
- Krause, C.M., Pörn B., Lang, A.H., & Laine, M. (1999). Relative alpha desynchronization and synchronization during perception of music. Scandinavian Journal of Psychology, 40, 209-215.
- Lähteenmäki, P., Krause, C.M., Sillanmäki, L., Salmi, T.T. & Lang, A.H. (1999). Event-related alpha synchronization and desynchronization in a memory-search task in adolescent survivors of childhood cancer. Clinical Neurophysiology, 110, 1-10.
- Mohl, W., & Pfurtscheller, G. (1991). The role of the right parietal region in a movement time estimation task. NeuroReport, 2, 309-312.
- Pfurtscheller, G. (1977). Graphical display and statistical evaluation of event-related desynchronization. Electroencephalography and Clinical Neurophysiology, 43, 757-760.
- Pfurtscheller, G., & Aranibar, A. (1977). Event-related cortical desynchronization detected by power measurements of scalp EEG. Electroencephalography and Clinical Neurophysiology, 42, 817- 826.
- Pfurtscheller, G., & Aranibar, A. (1979). Evaluation of event-related desynchronization (ERD) preceding and following voluntary self-paced movement. Electroencephalography and Clinical Neurophysiology, 46, 138-146.
- Pfurtscheller, G., Steffan, J., & Maresch, H. (1988). ERD mapping and functional topography: Temporal and spatial aspects. In G. Pfurtscheller & F. H. Lopes da Silva (Eds.), Functional brain imaging, Stuttgart, Hans Huber, pp. 117-130.
- Pfurtscheller, G., & Berghold, A. (1989). Patterns of cortical activation during planning of voluntary movement. Electroencephalography and Clinical Neurophysiology, 72, 250-258.
- Pfurtscheller, G., & Klimesch, W. (1990). Topographical display and interpretation of event-related desynchronization during a visual-verbal task. Brain Topography, 3, 85-93.
- Pfurtscheller, G., & Klimesch, W. (1991). Event-related desynchronization during motor behavior and visual information processing. In C. H. M. Brunia, G. Mulder & M. N. Verbraten (Eds.), Event-related brain research, London, Elsevier Science Publishers.

- Pfurtscheller, G. (1992). Event-related synchronization (ERS): an electrophysiological correlate of cortical areas at rest. Electroencephalography and Clinical Neurophysiology, 83, 62-69.
- Pfurtscheller, G., & Klimesch, W. (1992a). Event-related synchronization and desynchronization of alpha and beta waves in a cognitive task. In E. Basar, W.J. Freeman, W.-D. Heiss, D. Lehmann, F.H. Lopes da Silva & E.-J. Speckmann (Eds.), Brain dynamics, Boston, Birkhauser, pp. 117-128.
- Pfurtscheller, G., & Klimesch, W. (1992b). Functional topography during a visuoverbal judgement task studied with event-related
- desynchronization mapping. Journal of Clinical Neurophysiology, 9, 120-131.
- Pfurtscheller, G., & Neuper, C. (1992). Simultaneous EEG 10 Hz desynchronization and 40 Hz synchronization during finger movements. NeuroReport, 3, 1057-1060.
- Pfurtscheller, G., Neuper, C., & Mohl, W. (1994). Event-related desynchronization (ERD) during visual processing. International Journal of Psychophysiology, 16, 147-153.
- Schulter, G., Kreutzhaler, A., & Pfurtscheller, G. (1990). Ear dominance and laterality of cortical activation identified by event-related desynchronization. International Journal of Psychophysiology, 8, 283-295.
- Steriade, M., Gloor, P., Llinas, R.R., Lopes da Silva, F.H., & Mesulam, M.-M. (1990). Basic mechanisms of cerebral rhythmic activities. Electroencephalography and Clinical Neurophysiology, 76, 481- 508.
- Sternberg, S. (1966). High-speed scanning in human memory. Science, 153, 652- 654.
- Van Winsum, W., Sergeant, J., & Geuze, R. (1984). The functional significance of ERD of alpha rhythm in attentional and activating tasks. Electroencephalography and Clinical Neurophysiology, 58, 519-524.